PARAMETERS AFFECTING UNDERWATER VISION

Edward Aberle Ruckner

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

PARAMETERS AFFECTING UNDERWATER VISION

by

Edward Aberle Ruckner, Jr.

Thesis Advisor: Gary K. Poock

March 1972

Parameters Affecting Underwater Vision

by

Edward Aberle Ruckner, Jr.
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1963

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

ABSTRACT

The purpose of this study was to determine the effects of illumination color, viewing distance, and turbidity on a visual reading task in a totally dark, flooded environment. The reading task was to read a voltmeter and make a correct oral report of the reading. A total of 180 data points spread over 18 viewing conditions were taken for each subject. Seventeen military officers were used as subjects. Experimental conditions were presented in a random manner to all subjects. A statistical examination of the results showed that white or green illumination is better than red in reducing reading response time. Turbidity levels were significant in affecting both response time and number of errors, with both increasing as the Attenuation Coefficient (α) increased.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

The United States Navy has, in the past, acquired small multi-man, wet (internally flooded) submarines on an "as needed" basis. It appears that little formal engineering design preceded their conception and construction. This approach has resulted in a variety of swimmer delivery vehicles (SDV) which are peculiarly suited to a given mission and/or environment.

It would be desirable to have a standard SDV which could deliver a multi-man underwater demolition team (UDT) accurately and covertly in any of several geographical locations with their varying water conditions. In particular, the conditions of turbidity, and average depth (and hence ambient illumination) vary greatly in coastal waters around the world.

It is the purpose of this paper to investigate certain parameters affecting the visibility of instrumentation in a flooded environment, and to provide data which will be of practical assistance in equipping a vehicle to operate in an environment of known, or at least bounded, parameters.

This work has been funded by the Navy Electronics Laboratory (NEL) Human Factors Division, San Diego, California. Subsequent work in this area is being funded and will be conducted by Associate Professor G. K. Poock of the United States Naval Postgraduate School.

II. THE PROBLEM

Representatives of NEL, in their presentations on the current state-of-the-art construction of SDV instrument panels, indicated that instruments are mounted in a watertight container and sealed with a ¼ inch plate of plexiglass. The illumination is generally on the periphery of the individual instrument. Viewing is done through the swimmer's face mask, water, and the plexiglass.

With this probable method of construction in future SDV's, and being aware that coastal water conditions vary, the problem becomes one of optimizing the viewer's ability to read the instruments and at the same time conserve battery power, since the same battery will propel the vehicle and light the instruments.

For this thesis, three parameters will be examined: turbidity, color of illumination, and viewing distance.

III. THE EXPERIMENTAL METHOD

A. DISPLAY

The display used for this study was a Simpson 0-15 D.C. Voltmeter, model 1327, which has a rectangular illuminated surface with a 90 degree angular scale swept by a pivoting pointer. The numerals, indicia, and pointer are black on a white background. The actual meter face was replaced by a 1:1 photographic reproduction on heavy matte paper. This permitted determination of the brightness ratio and makes it possible to later use a negative display face with identical characteristics.

The brightness ratio of the test face was determined by replacing the face with blank white matte paper and observing a reflectance of 20 percent. A similar observation with a blank black matte gave a reflectance of 11 percent. This relatively high black reflectance was probably due to the sheen of the black photographic paper. The brightness ratio of 20:11 is approximately 2:1.

B. SUBJECTS

Seventeen subjects were used. All were military officer students at the Naval Postgraduate School. Subjects were selected on the basis of willingness and availability. None of the subjects wore glasses during testing. Volunteers who normally wore glasses either used contact lenses for 20/20 correction or were not accepted. No subject was color-blind. Subjects ranged in age from 24 years to 37 years.

C. APPARATUS

In order to simulate the underwater environment, a rectangular tank was constructed of 3/4 inch exterior grade plywood. A standard oval face mask was mounted in the center of one end. The tank was calked, sealed with a commercial yacht sealer, and painted black. The entire tank was then mounted on a frame of 2 x 4 pine with the center of the face mask 48 inches above the floor to allow subjects to be comfortably seated.

The test display, which was positioned inside a water-tight ¼ inch plexiglass box, was mounted in such a way that it was level with the face mask when placed inside the tank. Viewing distance was adjusted by moving the entire display box. Illumination of the display was accomplished with two General Electric number 44 6VDC bulbs located in the upper periphery. The green and red lighting conditions were obtained by placing Kodak Wratten gelatin filters around the bulbs. The red filter was a number 24 with spectral characteristic at 600 millimicrons. The green filter was a number 60 with spectral characteristic at 520 millimicrons.

A shutter was located between the face mask and the display to control the actual time of exposure to the subject. Timing, and shutter control were accomplished with a Lafayette Instrument Company Multi Reaction Timer, Model 6302 BX, coupled with a Lafayette Voice Time Control, Model 6602 A.

Reflectance of the photographic face was measured with a Weston Electrical Instrument Corporation light meter, Model 756. This type of meter was chosen because it measures directly in foot candles. The same light meter was used to determine the

voltages required to get the same apparent source intensity at the plexiglass/water interface for each of the three illumination colors.

The voltages to obtain .5 footcandle for the red, white, and green illumination colors were 2.5, 2.3, and 3.8 respectively.

Attenuation coefficient (α) for the different levels of turbidity was converted from the percent transmission measured on a monochromatic spectraphotometer with a 10 centimeter path. Readings were taken to correspond with the spectral characteristics of the Wratten filters. The range of attenuation coefficient for the three conditions, clear, mild, and dark may be seen in Table III. The spectraphotometer used was the "Spectronic 100" manufactured by Bausch and Lomb.

D. EXPERIMENTAL DESIGN

The 18 conditions of the display reading task (3 illumination colors by 2 viewing distances, by 3 levels of turbidity) were presented to each subject in three periods, each lasting approximately 30 minutes and corresponding to one level of turbidity. The division of each subject's test into three periods was necessitated by class scheduling and was probably beneficial in reducing fatigue and/or boredom. The following conditions were used in establishing the test design:

1. Each subject received all 18 conditions. However, subjects were divided into six groups with each group receiving the turbidity levels in different sequences to prevent data biasing due to any possible learning effect for a given turbidity level.

2. Each condition was presented to a subject 10 times for a total of 180 trials which constituted a completed "data run" on a subject. A total of 3060 data points was obtained on the seventeen subjects.

3. Display readings for presentation to the subject were selected from a table of random numbers. Readings were normalized about 7.5 volts with equal division among numbers from 0 to 7.4 volts and 7.6 to 15 volts.

4. Subjects response times and errors were the criteria on which the variables were evaluated.

5. Variables held constant were: ambient illumination (which was total darkness), display size, display contrast, and apparent source intensity.

E. PROCEDURE

The test conductor had available to him the timing apparatus previously mentioned, a rheostat to control the display dial setting and a monitor voltmeter to ensure the proper display setting. A variac to control display illumination was also available but was only used to compensate for the changes in color to achieve identical apparent source intensity.

Each subject was given a set of written instructions, which may be found in Appendix A. In addition, each subject was given amplifying oral instructions on how the apparatus operated and what his response to the task was to be. Speed and accuracy were emphasized. The subject was then seated in a chair and the height adjusted so his face could rest comfortably in the mask. The shutter was then opened and the subject was allowed to study the

display to become familiar with the indices and numerals. After the subject was satisfied, a trial of 20 readings was conducted to ensure familiarity with the procedure. Errors during the preliminary trial were shown to the subject to make him aware of the necessity for accuracy in reading the meter.

When the subject had been thoroughly prepared, a series of 60 readings were taken, 10 at each of the two distances for each of the three colors of illumination. Before each reading, the subject was given an audio warning.

Response times and errors were recorded manually by the test conductor.

IV. THE RESULTS

Response times for each subject in each condition were averaged over the correct responses to yield one data point per subject per condition. These data were then analyzed with a 3 x 3 x 2 factorial Analysis of Variance (ANOVA). Table I summarizes the results of the ANOVA.

No interactions were significant at any level. Color of illumination was significant at the .001 level and was investigated with the Duncan Multiple Range test. This showed no significant difference between white and green illumination while red varied significantly from both of the other colors, giving a longer response time. See Figure 1.

Turbidity was significant at the .025 level. In this case, each condition was significant from the other two. Mean response times were 1.74, 1.85, and 1.95 seconds for the clear, mild, and dark conditions respectively. (Table III)

Viewing distance was significant only at the .25 level with mean response times of 1.81 and 1.89 seconds for the 8 inch and 13 inch viewing distances respectively.

Errors in response were designated as over estimation or under estimation and the amount noted. A non-parametric test of runs showed that over and under estimation occurred randomly. Seventy-seven percent of the errors were of the magnitude .2 volt. Magnitude, therefore, was not considered important and analysis was conducted on the absolute number of errors per subject per condition.

A 3 x 3 x 2 factorial ANOVA on the number of errors showed no significance of any interaction between treatments and no significance of any treatment except turbidity, which was significant at the .05 level. Table II summarizes the results of this ANOVA.

A Duncan Multiple Range test showed that the dark condition yielded significantly greater errors than either the clear or mild condition. The mean number of errors in ten trials was 1.59 and 1.64 for the clear and mild conditions respectively, but increased sharply to 2.17 for the dark condition. (See Figure 2.)

V. CONCLUSIONS AND RECOMMENDATIONS

Based on the information provided by the analysis, it would appear that a white or green illumination should be used in a totally dark environment to keep response time to a minimum. There does not appear to be any factor which the design engineer can control to reduce the number of errors. Training and familiarization with the equipment may reduce errors to within acceptable bounds, since most of the subjects complained about the graduations and indicia on the display used.

Subjects stated a general preference for the green illumination although it did not show any statistical dominance.

It is recommended that further study in this area be done using a negative of the display face used here, and that ambient illumination, which almost always exists in coastal waters during daylight, be investigated.

APPENDIX A. INSTRUCTIONS TO SUBJECTS

You are acting as a subject to test responses to a visual stimulus underwater with various conditions of murkiness, viewing distance, and color of illumination.

Sit comfortably in the chair and place your eyes and nose in the face mask; no light should leak around your face and you will have to breathe through your mouth.

In front of you is a plastic shutter which will move to expose the stimulus - in your case a volt meter with a white face and black numerals and markings.

Your task will be to correctly read the meter and give a verbal report of what you saw. Your verbal response will cause the shutter to close. Avoid coughing, thinking out loud, or making any other noises which will cause the shutter to close before you are ready.

Do not remove your face from the mask until you are told to do so.

Work as quickly as possible but try to make your response accurate.

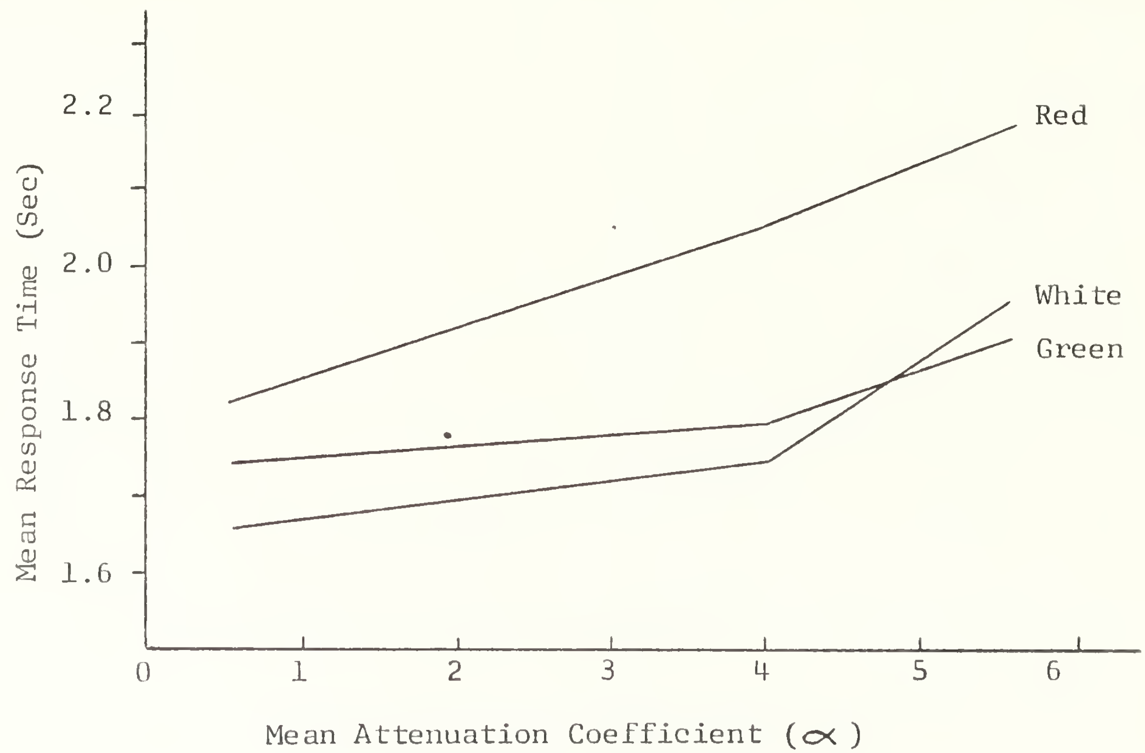

Figure 1. MEAN RESPONSE TIME VS MEAN ATTENUATION COEFFICIENT

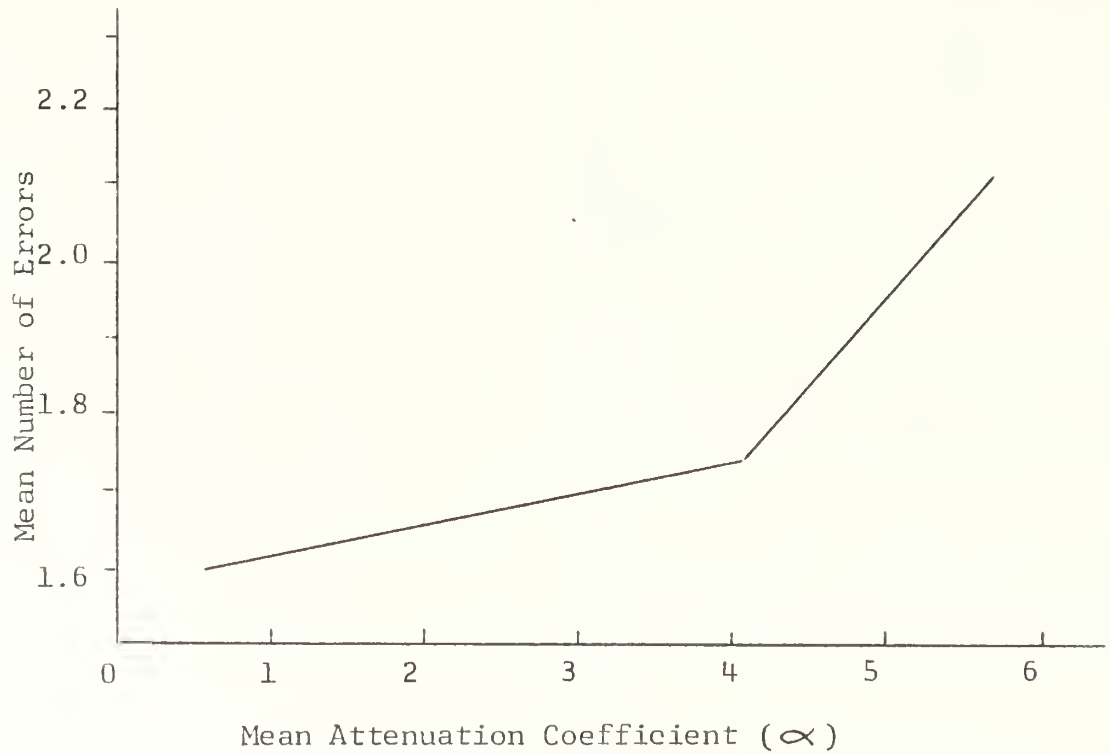

Figure 2. MEAN NUMBER OF ERRORS VS MEAN ATTENUATION COEFFICIENT

TABLE I

ANALYSIS OF VARIANCE

RESPONSE TIMES

SOURCE	DF	SS	MS	F	p
TURBIDITY (T)	2	2.2678	1.1339	3.722	.025
COLOR (C)	2	4.1072	2.0536	6.742	.001
DISTANCE (D)	1	.4936	.4936	1.620	.250
T x C	4	.7688	.1922	.631	NS
T x D	2	.6594	.3297	1.082	NS
D x C	2	.2077	.1038	.341	NS
T x D x C	4	.1431	.0357	.117	NS
ERROR	288	87.7391	.3046		
TOTAL	305	96.3867			

TABLE II

ANALYSIS OF VARIANCE

NUMBER OF ERRORS

SOURCE	DF	SS	MS	F	p
TURBIDITY (T)	2	20.99	10.49	3.113	.050
COLOR (C)	2	8.95	4.47	1.326	NS
DISTANCE (D)	1	2.56	2.56	.759	NS
T x C	4	8.73	2.18	.647	NS
T x D	2	3.34	1.67	.495	NS
D x C	2	1.30	.65	.193	NS
T x D x C	4	6.98	1.74	.516	NS
ERROR	288	768.59	3.37		
TOTAL	305	821.44			

TABLE III

RANGE OF ATTENUATION COEFFICIENT (α)

TURBIDITY LEVEL	ATTENUATION COEFFICIENT LOW	MEAN	HIGH
CLEAR	.18	.53	1.60
MILD	3.26	3.92	4.48
DARK	5.29	5.65	6.69

BIBLIOGRAPHY

North American Aviation, Inc., Ocean Systems Operations Technical Report T7-827/020, Underwater Display Legibility as a Function of Display Format, Color, Brightness and Viewing Distance, by R. A. Beam and R. M. Shannon, June 1967.

Kinney, Jo Ann S., Luria, S. M., and Weitzman, Donald O., "Visibility of Colors Underwater," Journal of the Optical Society of America v. 57, no. 6, p. 802-809, June 1967.

U. S. Naval Submarine Medical Center Report Number 551, The Underwater Visibility of Colors with Artificial Illumination, by Jo Ann S. Kinney, S. M. Luria, and Donald O. Weitzman, October 1968.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Assoc. Professor G. K. Poock, Code 55pk Department of Operations Research and Administrative Sciences Naval Postgraduate School Monterey, California 93940	1
4.	Chief of Naval Personnel Pers 11b Department of the Navy Washington, D. C. 20370	1
5.	Naval Postgraduate School Department of Operations Research and Administrative Sciences (Code 55) Monterey, California 93940	1
6.	U. S. Navy Electronics Laboratory Gerald Miller, Code 3400 271 Catalina Boulevard San Diego, California 92152	2
7.	LCDR Edward Aberle Ruckner, Jr., USN 1913 Sleepy Hollow Lane Annapolis, Maryland 21401	1

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Parameters Affecting Underwater Vision

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis; March 1972

5. AUTHOR(S) (First name, middle initial, last name)

Edward Aberle Ruckner Jr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1972	25	3

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

The purpose of this study was to determine the effects of illumination color, viewing distance, and turbidity on a visual reading task in a totally dark, flooded environment. The reading task was to read a voltmeter and make a correct oral report of the reading. A total of 180 data points spread over 18 viewing conditions were taken for each subject. Seventeen military officers were used as subjects. Experimental conditions were presented in a random manner to all subjects. A statistical examination of the results showed that white or green illumination is better than red in reducing reading response time. Turbidity levels were significant in affecting both response time and number of errors, with both increasing as the Attenuation Coefficient (α) increased.

Security Classification

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
ual reading task						
erwater visibility						
or of illumination						
bidity						